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Convenient connection technology data model supporting optimized information exchange between CAx-systems

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ABSTRACT
In the automotive industry, the number of multi-material bodies is increasing steadily. The background for this rise is, that the body weight can be reduced due to a mix of different materials, by almost the same material costs. This technology requires a high number of different kinds of connection types, which requires the implementation of a high amount of meta data. This large date volume plays a crucial role in the development process, especially in terms of the applied CAx-environment. A big issue is the data exchange between the different areas design, analyses and manufacturing. By optimizing the data exchange process, data quality can be improved and data quantity can be reduced. The present paper focusses on an approach of a new data model, which deals with data processing and storage, in an attempt, to further reduce the effort of data management and costs.

KEYWORDS
Connection techniques; CAD-CAE integration; knowledge-based engineering; design meta information; data exchange; joining technology

1. Introduction

In today's increasingly and progressively globalized economy, which has produced a very volatile and ever-changing business market, it has become ever more difficult for automobile producers and manufacturers to identify, analyze, and fulfill consumer desires and their respective expectations. This process is drastically exacerbated by the consistent and intense inter-competition between members of the automobile manufacturing industry [6]. This means that the automotive market is elevated and consolidated by innovations and inventions. One important point to achieve is increasingly shorter times to market by automating and optimizing the development processes. The average development time of a vehicle has been reduced in the past four decades from nearly seven years to pretty much about two years, today [4]. Due to the advanced globalization and increasing competitive pressure, it is important for car manufacturers to find market niches. One important influencing factor in the car development includes technologies for the reduction of energy and fuel consumption, i.e. by lightweight design. On the one hand, it is imperative to keep costs low and on the other hand, it is ever more important to reduce the total weight of a vehicle. Both factors - weight and cost-reduction, respectively - are required to maintain competitiveness. A good leverage point for a total weight reduction is to reduce the mass of the body. Important to know is, that modern bodywork consists of different types of materials, including but not limited to: any kind of steel, aluminium and carbon fiber.

The weight of an aluminum body is about 30-40% and that of a carbon fiber body is about 50% less than those of a comparable body made by commercial steel. Moreover, there are the production costs to be considered as well. Strictly comparing the costs of production, carbon fiber is much more expensive than aluminum, with steel being the cheapest material available for bodywork mass production. Due to these limitations caused by factors of weight and cost, a combination of the materials represents an advantageous approach. The trend goes into the direction of lightweight bodies, including multi-material solutions. An important issue for the combination of various materials is how they can be interconnected. This requires new connection technologies, e.g. bonding, bolds, rivets, screws, multi-material welding, etc. Besides lightweight design and cost aspects, there are several additional factors that impact automotive body development, e.g. stiffness and durability, crash and safety-related aspects, as well as topics from production [5].

In this context, the present paper focuses on investigations in an important field of automotive bodywork development: the computer-aided design and layout of connection technology. As a basis, the state of art is introduced and the different types of connection technologies

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in automotive body design are discussed. Subsequently, a simulation process is formulated and evaluated in view of different quality and development performance criteria to support integration of knowledge-based methods into existing design workflows [7].

Finally, the paper introduces an approach of a data model for a smart integration of knowledge-based design methods and design automation. Target of this approach is to improve data quality and reduce data quantity to a minimum by an optimized data model. This supports the data exchange process between the different areas design, analyses and manufacturing. Thus, the approach has some advantages but limitations as well, which are described and discussed in chapter 4.

2. Problem statement

As introduced in the previous section, it is important to find an optimal solution for design automation and optimization of connection technology in the automotive industry. Since today's automotive design processes are carried out completely in computer-aided design- and simulation environment, the present approach emphasizes focusing the application in common CAx–systems (CAx – computer-aided x, where x is a placeholder, e.g. CAD, CAE, etc.). This in turn provides an enhancement of the data exchange between design, simulation and manufacturing development.

To enhance the data exchange process, it is important to know, which data is needed in which area of development. Important key issues include the aspects of which data does the CAD-engineer need and which data is transferred to the computer-aided engineering (CAE) department? Additionally, what are the requirements of simulation processes? Which file format is needed for simulation (pre-processing) and how can they be created? Which parameters are created in CAD and transferred to computer-aided manufacturing (CAM) processes and which additional information is needed there? The main issue is in which ways is it possible to transfer connection technology data from CAD-environment into CAE-environment? Which file format is best suited for this transfer? How is it possible to guarantee that the transmitted information is received in the CAE-system? Currently, there are many ways to transfer data from the CAD-environment into the CAE-environment, i.e. STEP (STandard for the Exchange of Product model data) or JT (Jupiter Tesselation).

Having stated that every discipline requires various information to fulfill its development tasks. This variety of values must be collected and can be bunched together in a comprehensive data model or in a database structure. The idea of a unified data model shall be seized up in a way that it is possible to be used in most areas of application. In this context, the presented data model is based on an optimized process to decrease development costs and support reduced development time in total.

3. State of the art

Currently there are just a few standards or regulations available for connection technology data models or for transfer of connection technology data. One of these standards is the xMCF-standard or χMCF-standard (Extended Master Connection File), which is based on an xml file format. This standard, as the previous stated data format JT, is further discussed in the chapter 4.

From the viewpoint of an engineering supplier a big issue is that projects are processed together with different OEMs. Why is this such a big problem, especially in terms of data management and data exchange? A lot of car manufacturers (OEMs) such as Renault or Opel have not clearly announced, which systems, tools or processes are used in their development projects. They do not make clear specifications regarding the use of a certain software, tools, systems or processes to engineering supplier. On the other hand, there are some OEMs like BMW or Daimler, which specify the development environment and data management-related aspects with high accuracy. Consequently, this leads to the fact that a supplier must deal with different software (for example CAD programs e.g. CATIA [https://www.3ds.com/] or NX [https://www.siemens.com/NX]). The different systems and tools are limited due to scarcity of the currently available versions on the market. Despite that, every OEM uses different data management systems and different development processes.

There is another big issue regarding the creation of the hole connection technology in such a project. Currently there are several possibilities how this creation can take place, i.e. import of connection technology in CAD- or CAE-environment, or the import of the connection technology due to a list, like an Excel-list, as well as many other. These possibilities may differ in each project, mostly due to the requirements an OEM purports. Due to this issue, it is important to find an optimal solution for creation and exchanging of connection technology, which is applicable for several projects.

To achieve a shorter development time, more and more applications of virtual product development are applied. According to vehicle bodywork, each body design starts with a general definition of the product specifications and an exterior styling proposition [8], [11]. The next step includes the body packaging development. In this phase, CAS data is transferred into CAD-environment. From this moment on, the design of the

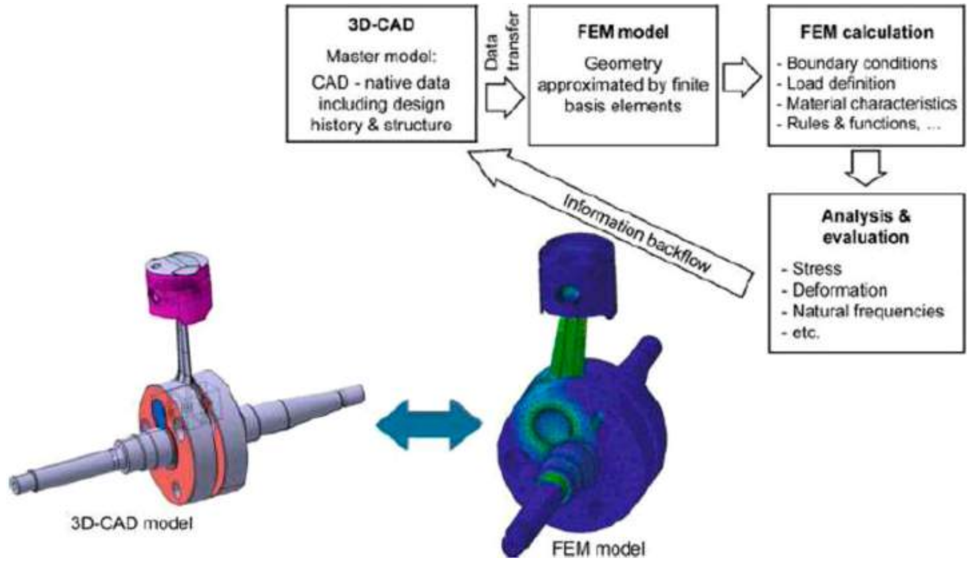

Figure 1. Data flow in a FEM process of a 1-cylinder engine crankshaft [4].

bodywork starts under a variety of technical aspects. By use of CAE-systems, the design is continually refined and due to the detection of problem areas, an optimization cycle (CAD/CAE integration process, cf. Fig. 1) between CAD and CAE is started[1], [2], [12].

During the whole development process, this cycle runs through several times. The same cycle takes place between CAD and CAM. CAD data is transferred into a CAM-environment, where it is examined for production-related facets. At this juncture, the enhancements are transferred back to the CAD- environment where necessary modifications are performed[2], [9], [11]. An important issue in this process includes the connection technology in total. Connection technology is used to combine several components of an automotive bodywork. A favorable connection technology that is still currently in use is spot welding. Exemplary, about 5000 spot welds are applied in a mid-size car steel body.

Apart from spot welds, there are also many other types of connection technology in such a body, i.e. a few meters of welding lines and a few meters of different kinds of adhesives, as well as a low number of weld studs (cf. Tab. 1

Table 1. Types of connection technologies - Volvo V90 and V70 [10].

	V90	V70
Spot welds	5250	4170
Arc weld [m]	4.9	5.5
Laser weld [m]	4.4	5.7
Laser braze [m]	0	1.3
Adhesive - Epoxy [m]	0	24.9
Adhesive - Rubber [m]	69.6	16.2
Hotmelt [m]	7.2	19.8
Antiflutter [m]	2.6	2.8
Weldstuds [#]	247	190

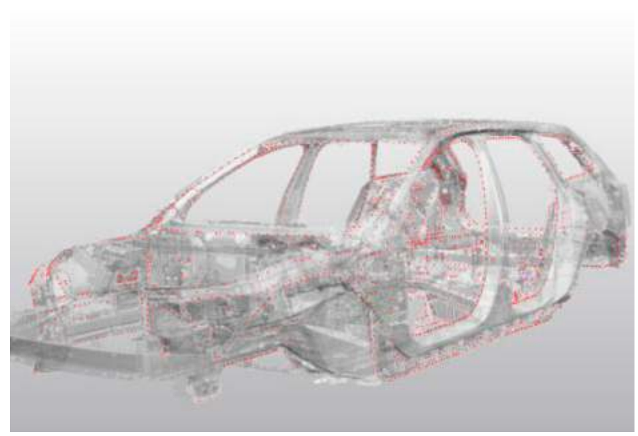

Figure 2. Volvo V90 Car body – spot welds are displayed as red dots [10].

and Fig. 2) [10]. Due to this high amount of different types of connection technologies a significant effort in design, simulation as well as production is necessary. All required information concerning the applied connection technology in a body-in-white development process is mostly created in the CAD-environment as a data model. This information may contain (for the example of a spot weld) the spot weld dimensions and positions, adjacent sheet metal parts, as well as other data. This generated information is supplied to the CAE simulation process to give a useful verification of stiffness, durability and deformation behavior, for example in case of a crash scenario.

The next step is to supply the CAM-engineer with this optimized CAD data model. Furthermore, the production engineer must prove that the accessibility of weld robots is ensured. A considerable extra effort for definition of the meta data is added to the already mentioned effort for the generation of spot welds. Regardless, meta data is important for the exchange process because it contains the type of connection, the number of circuits of the connection, the involved components as well as the material, among others.

Another important issue includes the positions of the connection points, since this provides information about safety-relevant areas [12]. As already mentioned before, more and more multi-material bodies are produced. These require new and more technologies - in addition to spot welds - in terms of connecting two or more different materials components together.

Today, there is a variety of standards available for the data exchange in the field of connection technology between CAD, CAE and CAM processes. To make matters worse, different OEMs have different suggestions on how a project should proceed, i.e. the specification of different CAD- and CAE-tools.

4. Data model

To decrease the information gap between design, analyses and manufacturing, a unified data model is a common approach. In the next sub chapters an approach of such a data model is introduced and discussed in detail.

4.1. General approach of the data model

The target is to create a data model, which includes the already mentioned issues and which optimizes the data exchange process between the different fields in the development process. The data model should be applicable for most of currently used CAx-systems and -tools within the development environment of different OEMs. The focus of the present approach (cf. Fig. 3) lies on the data volume of connection technology of automotive multi-material bodywork.

Fig. 3 shows the approach by an exemplary application of weld spot development, including the main components of the data model. In an overview, the data model consists of a CAD- and CAE-environment, a Product Data Management (PDM)-system and a connection technology exchange tool, that is called CTXT. Meta data and geometry information of an exemplary weld spot defined within CAD-environment is transferred into CTXT. On the one hand, the CTXT tool communicates with the CAE-environment to forward all necessary data. On the other hand, the CTXT interacts with the PDM-system to supply a data base with required information.

In this way, CTXT is transferring all important data into the CAE-environment, where these data are prepared (CAE pre-processing) for simulation processes. After the simulation, the CAE post-processing step take place, where the simulation results are summarized and an output file is generated. After handing-out the whole CAE-process, the obtained data are returned to the CTXT. Henceforth, it is possible that the CTXT is communicating with the CAD-environment - to enhance the CAD-model - and to enlarge the database of the PDM-system.

4.2. General information of the connection technology exchange tool

As previously stated, the CTXT is linking the CAD-environment with the CAE/CAM-environment, as well as a data storage system/PDM-system. Its task is to communicate with all of them in a way that a manually conversion of different data formats is not necessary. A brief overview of the CAD-environment shows that by the existing example, two sheets are connected by a weld spot. Both, sheet 1 and sheet 2 carry some meta data. In this example, these are the thickness of the sheets, as well as the material. In the next few lines in the product tree, the necessary information for the welding point is displayed. These contain the welding point (1001 – green box), the surface normal (important for the CAM-engineer), the welding point coordinates (necessary for CAD, CAE and CAM applications), the geometry for visualization in 3D (CAD, CAE relevant) and some additional information, i.e. spot diameter (required in all three domains). This information and some other data (which is not displayed in this example) is transferred into the CTXT. A possible way to transfer these data into the CTXT is due to a neutral file format like XML, JT or STEP (see chapter 4.3).

After conversion and preparation of the data, the CTXT is communicating with the CAE-environment. The data is transferred into a CAE pre-processing process, in which all necessary steps are done, so that the simulation process can take place. After simulation, the data are prepared in the CAE post-processing process for output. From now on the generated output data is transferred back into the CTXT. This whole process is performed like a loop (CAD-CTXT-CAE-CTXT-CAD). In this example the CTXT stores and handles all necessary CAD data, like the meta data and the geometry of the exemplary 2 sheets, as well as of the welding points, all generated CAE data (i.e. mesh for FE-calculation) and if necessary the whole data the CTXT receives from a PDM-system. The ulterior motive to use a PDM-system is that it is easier to store and use data, especially for a multi-user system. A second reason for PDM is that every area (CAD, CAE, CAM ...) needs different types and volumes of data. E.g. not every domain is interested in the complete data sets - they just need some

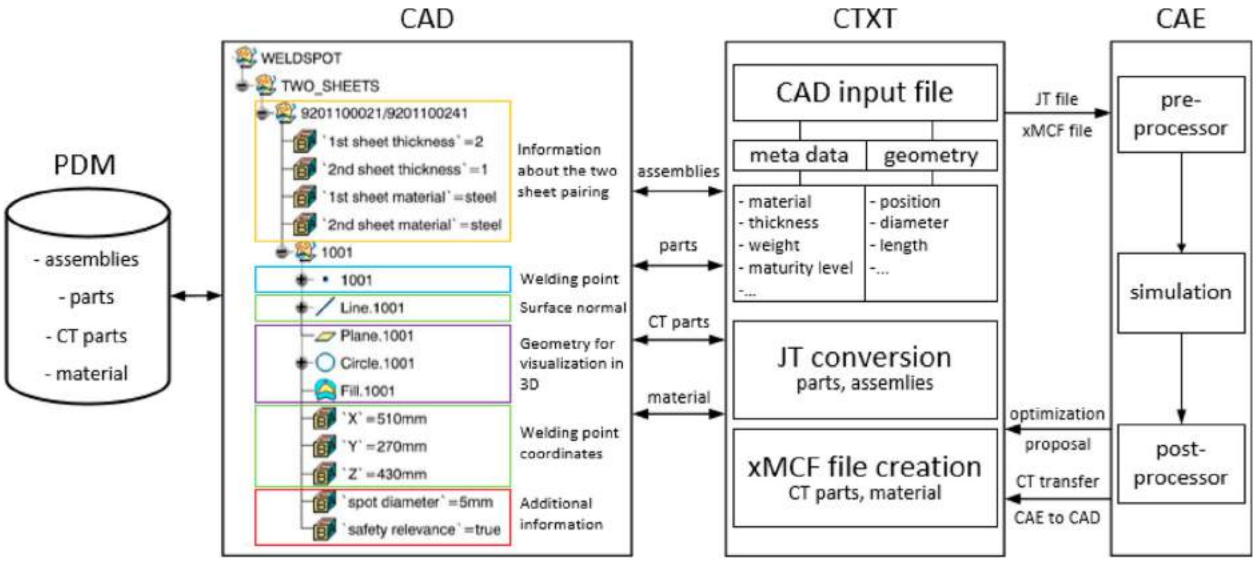

Figure 3. General layout of a connection technology data model.

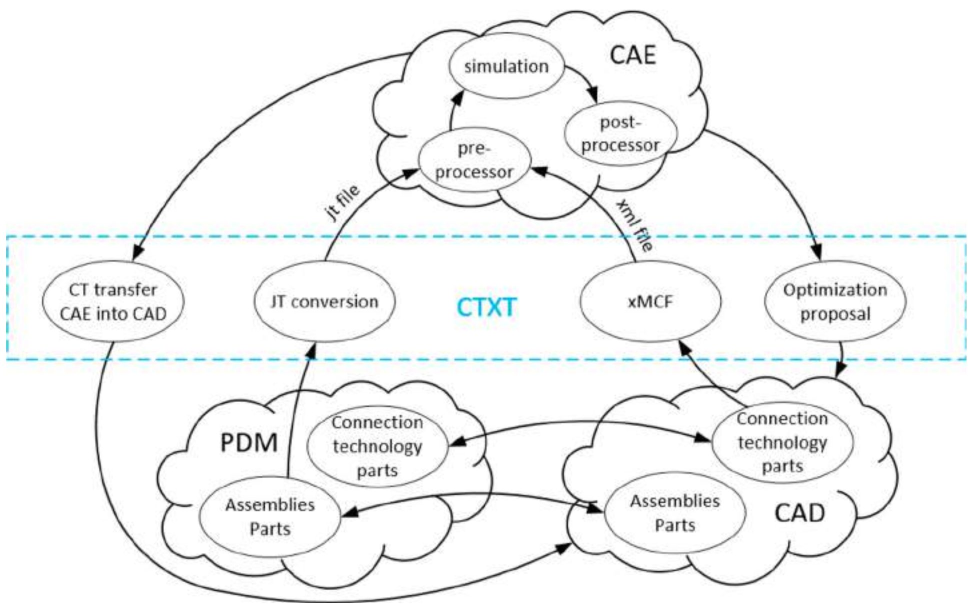

Figure 4. Overview of a data exchange process between CAD and CAE.

relevant information. In this case, reduced data sets can be transferred from the PDM-system. Another important point for a PDM-system is that every area should work with the same data records. In the field of connection technology, a freeze of the connection technology data takes place frequently. These freeze guarantees that the CAD-engineers have the same data status as the CAE- or CAM-engineers.

Fig. 4 shows, how a standard data exchange process works. To give a brief overview to this process, it is important to know that the main workflow goes from the CAD-system into the CAE-system. The CAD-tool is normally the master of the communication. Two different kinds of data (geometry plus meta data and joining data plus meta data) are transferred into a CAE-system. In this example, it is represented as a CAE-tool (i.e. ANSA [https://www.beta-cae.com/ansa.html]). Before the data exchange process can talk place, it is a precondition, that data matching takes place. Additionally, it is a must to consider the different file formats for the exchange process. As seen in Fig. 4, the file format JT is used for the geometry exchange process, as well as xMCF (as an xml file) for the connection technology data exchange process. Finally, a certain process takes place that enables feedback transfer from the CAE-environment into the CAD-environment. This feedback process is an important part of the hole exchange process, because it starts the change-management-process. The way how this change-management-process works, is explained in the following short example.

After running through the whole analyses process, the CAE-engineer gets the output/ results of the simulation. Based on these results, the CAE-engineer makes some improvements to the connection technology. One of such an improvement could be the replacement of the connections to a different position (i.e. replacement of seam welds, spot welds . . .). Another improvement could be, that due to the present results a higher or lower number of connections is necessary to fulfill the necessary requirements in each area of analyses (durability, NVH (Noise Vibration Harshness), crash and CFD (Computational Fluid Dynamics)). These two and some other improvements will feed back to the CAD-engineer, that an optimization of the CAD-model can take place.

4.3. Data transfer between the different CAx-systems

Another discussion issue is which file formats can be used for the data exchange process. For exchanging assemblies/parts (no CT parts), a converted STEP or JT file instead of the native CAD data (i.e. CATIA or NX files) is a common way. Both, converted data and native data, are possible to be implemented into most CAE or CAM pre-processors, like ANSA. An important issue that is an advantage for a converted file – like JT – is the file size. Fig. 5 shows that a complete JT-file is approximately one-tenth and a JT-ULP-file (ULP . . . Ultra-Lightweight Precise) nearly a hundredth of the size of a non-converted NX file. This smaller file size allows a faster input process. In most cases the neutral file format is geometrically accurate enough for the pre-processing steps. Disadvantage of using a JT-file include the converting process from native data to a JT-file. This converting process can cause some problems and is time-consuming [6].

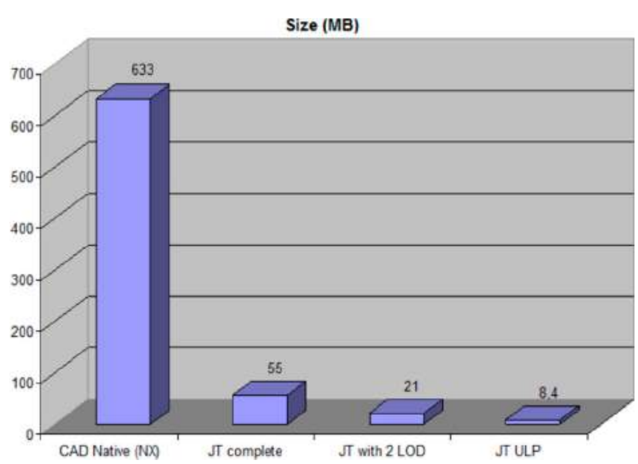

Figure 5. Comparison of file sizes – NX native data format vs. the neutral data format JT [6].

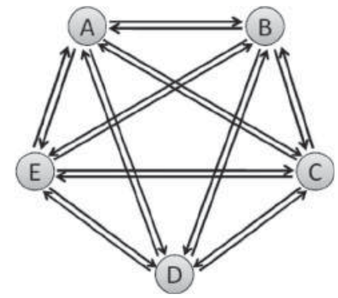

Figure 6. Data transfer - native format [13].

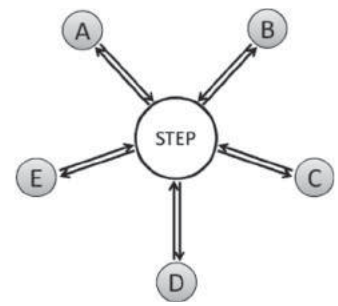

Figure 7. Data transfer - neutral format [13].

In the literature, there are numerous considerations in which different file formats geometry data can be transferred. In the case of a native format, more converters are necessary, which leads to the fact that each tool (displayed by A, B, C, D, E in Fig. 6 and Fig. 7) needs its own data converter. Another disadvantage is, that new tools need a separate converter for their integration (see Fig. 6). A good leverage point from the viewpoint of an automotive supplier is to use a neutral data format for the exchange process. In case of a neutral data exchange format a lower number of converters is needed because all tools can interact in one file format (see Fig. 7) [13].

An important format, which is often used for data exchange (in the automotive industry), as well as in the present work is STEP. STEP-files are mostly used for exchange processes in the field of CAx-data. On the contrary, STEP has a disadvantage in the field of visualization. Due to this disadvantage the file format JT is used to transfer CAD data (with an exact geometry) into a CAE-environment (no exact geometry – can be displayed in form of e.g. a mesh).

Another issue related to the data exchange process includes the data quality and quantity. As previously mentioned, a mid-size vehicle body consists of approx. 5000 connection elements and many other types of

Table 2. Necessary information by an example of spot welds.

CAD	CAE	CAM
coordinates (x, y, z) diameter	coordinates (x, y, z) diameter material	coordinates (x, y, z) diameter material surface normal technology (laser, friction welding, ...) manufacturer of welding device

connection technologies (cf. Tab. 1 and Fig. 2). The data model must guarantee that the data of all of them are correctly transferred into the CAE-environment. This high amount of data leads to the fact that the transfer needs a certain time.

4.4. Necessary data and classification of relevant connection types

Every type of connection technology is characterized by different parameters and attributes. Tab. 2 gives an exemplary overview for a spot weld and describes which data is needed by a design engineer (CAD), by an analyses engineer (CAE) and by a production engineer (CAM).

In the example shown in Tab. 2 spot welds are completely described by their coordinates (x, y, z-coordinate), diameter, material, technology and some additional parameters, e.g. type and manufacturer of welding device, required current density for welding, etc. Apart from spot welds, every type of connection technology needs its own attributes and parameters to be clearly characterized. A big issue is that every manufacturer prefers different types of connection technologies. This leads to the fact that the data model must be able to manage every currently used connection technology on the market. If this is not the case, it can lead to a problem in the data flow. The required definition to maintain data consistency comprehensively, is based on the xMCF standard [3]. The various kinds of connection technologies differ from each other by their geometrical shape, manufacturing process, material, mechanical properties etc. In the data model a distinction is made between the following three types of connection technology [3]:

1) 0d-connections: spot welds, rivets, bolts, screws ...
2) 1d-connections: seam welds, adhesive lines, hemming flanges ...
3) 2d-connections: adhesive faces ...

This classification can be justified as follows: Spot welds are in the class of 0d-connection technology (as idealized spot welds), described by a coordinate vector and its diameter. Fig. 8 shows a seam weld, which represents a 1d-connection technology that is described by a curve (discretized by points) and an additional parameter.

Figure 8. Seam weld (example for a 1d-connection technology) [3].

Representatives for 2d-connection technologies are idealized adhesive surfaces, which are described by using geometrical information, e.g. tessellations and faces [3].

Currently the most types of connections in a vehicle, are 0d-connections, like spot welds, rivets .... The trend of car manufactures goes to reduce the number of 0d-connections and implement more and more adhesive-connections. For such changes and due to the introduction of new types of connections it is important, that the exchange process is generic and adaptable, in order to address various project- environments and CAx-systems.

4.5. Advantages of a unified data model

As a result, a file format for data exchange must be found, which is compatible for all tools applied within the CAD-, CAE- and CAM-environment during the development process. This requires the conversion of the information - that is transferred between the different systems. Data quality plays an important role; each conversion is an additional error source. Therefore, a very important reason for a unified data model is, that there is no necessity for extra conversion [3].

Based on xMCF, a standard for describing connections and joints in the automotive industry, the data model can handle all relevant information of connection technologies, which are used in the automotive industry. Due to the reason of the use of several systems and that the model must be able to handle all types of connection technology, a high amount of data is created. From the viewpoint of an automotive supplier it is also necessary, that every connection technology can be applied in different projects, independent from the required level of information details. A very important point is that due to the advance of the technological development, i.e. the use of new materials in the field of the automotive bodywork, new types of connection technologies are expected. In this way, the data model must be generated in a way that enables to add any new type of connection technology.

As mentioned before, frequently data freezes take place in the field of connection technology. A unified data model must guarantee that every engineer, no matter in which domain (CAD, CAE ...) receives the same data status.

5. Conclusion

Due to the progressing globalization in automotive industry, it is more important than ever to automate the processes of design, simulation and manufacturing. This automation results in a considerable acceleration of production development and can also increase the process reliability. In conclusion, it can be mentioned that there is a high potential for optimization of the data exchange process, especially in the field of multidisciplinary development of connection technology.

A possible way to optimize the information exchange process is provided by the implementation of a unified data model. This data model gives a good leverage point for a smart integration of knowledge-based design methods and design automation. The target is to improve data quality and reduce data quantity due to a tool, called CTXT. This tool is working with file formats for data exchange, which are compatible for all tools applied within the CAD-, CAE- and CAM-environment. Data quality plays an important role; each conversion is an additional error source. Therefore, an important advantage of using a unified data model includes that there is no necessity for extra data conversion i.e. by neutral file formats [3].

By introducing a new approach for a comprehensive connection technology data model, the findings of the present contribution can support the enhancement of automotive bodywork development processes. Frequently data freezes take place in the field of connection technology. A unified data model guarantees that every engineer, no matter in which domain (CAD, CAE ...) receives the same data status.

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